Smart and Sustainable Data Centres:
Intelligent Monitoring for Energy Efficiency, Power Quality and Reliability

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1. Background and Motivation

- Data centres are rapidly expanding to support cloud computing, AI and digital services, leading to a significant increase in electricity demand worldwide.
- Key challenges include energy efficiency, power quality, reliability, operating cost and environmental impact (GHG emissions).
- Mission-critical electrical infrastructure (transformers, switchgear, UPSs, generators, PDUs) and renewable energy integration are essential for modern data centres.
- There is a need for intelligent monitoring, control and decision support to optimise grid-connected and off-grid operation, integrate multiple energy storage technologies and enhance resilience and sustainability.



2. Research Objectives

1. Develop an intelligent monitoring and decision-support framework for data-centre electrical systems.
2. Assess energy efficiency, power quality, reliability and operating costs.
3. Investigate the integration of renewable generation and multiple energy storage technologies.
4. Examine grid-connected and off-grid operating scenarios with appropriate control strategies.
5. Evaluate the technical and economic feasibility under Canadian conditions.

3. Literature Review, Research Gap and Novelty

Current State

- Commercial platforms (e.g., Edgecom Energy, Schneider, Siemens) provide real-time monitoring and operational analytics.
- Existing studies focus on energy optimisation, cooling efficiency and reliability improvement.
- Limited integration of multi-energy storage and off-grid strategies for data centres.

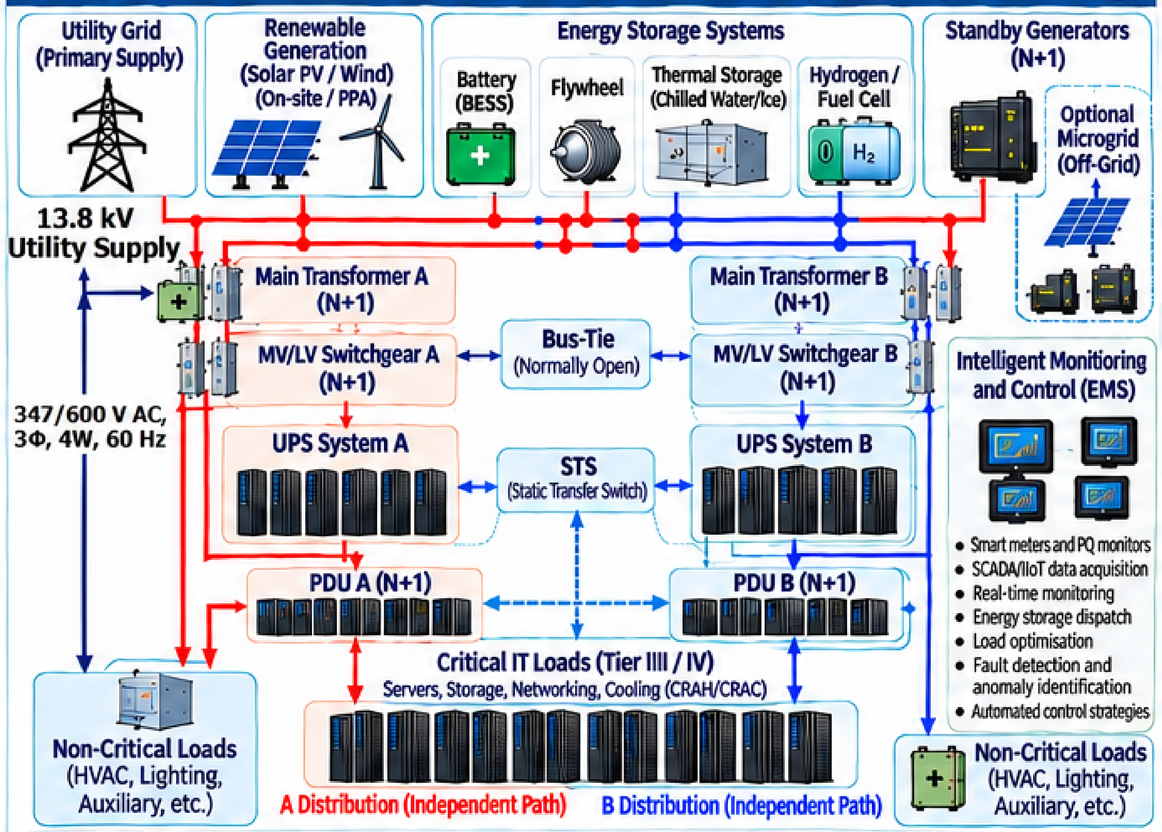
Research Gap

- A coordineaed framework that jointly considers electrical performance, power quality, storage dispatch, grid/off-grid control and Canadian cost analysis is limited.

Proposed Contribution (Novelty)

- An integrated monitoring, control and decision-support framework that coordinates A/B power distribution, renewable generation, multi-technology energy storage and grid/off-grid operation to optimise energy efficiency, power quality, reliability and total cost for data-centre electrical systems.

4. Proposed System Architecture (A/B Distribution with Redundancy and Intelligent Monitoring)



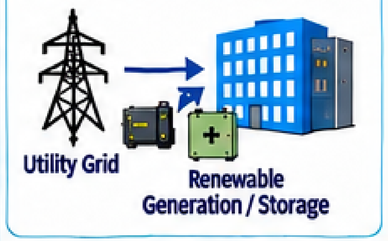
5. Energy Storage Technologies for Data Centres

Technology	Typical Application	Key Advantages	Considerations
Lithium-Ion Battery (BESS)	Short- to medium-duration (minutes–hours)	High efficiency, mature technology, fast response	Degradation, fire safety, cost, lifetime
Flywheel Storage	Short-duration (seconds–minutes)	High power, long cycle life, fast response	High initial cost, limited energy capacity
Thermal Storage (Chilled Water/Ice)	Cooling load management	Reduces electrical peak demand, lower cost per kWh (thermal)	Space requirement, integration with HVAC
H_2 Hydrogen / Fuel Cell	Long-duration (hours–days)	High energy capacity, low emissions	Higher cost, infrastructure required, efficiency
Hybrid System	Combined solution	Complementary strengths, improved reliability	Complex control strategy, higher initial cost

6. Grid-Connected vs Off-Grid Operation

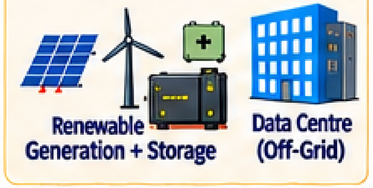
Grid-Connected Operation

- Reliable utility supply with backup generators and storage.
- Opportunities for peak shaving, demand response and renewable integration.
- Grid support services (e.g., frequency response).
- Lower initial investment.



Off-Grid / Islanded Operation

- Independent operation using renewable generation, storage and backup.
- Advanced control strategy for stability, power quality and reliability.
- Applicable to remote areas or locations with high electricity cost or grid constraints.
- Potential for lower long-term electricity cost and higher energy security and resilience.



7. Research Methodology and Techno-Economic Evaluation

Research Methodology

1. System modelling and simulation (e.g., ETAP / MATLAB / Simulink).
2. Integration of intelligent monitoring and control strategies,
3. Scenario analysis: grid-connected, off-grid and hybrid operation,
4. Performance assessment (energy efficiency, power quality, reliability, emissions).
5. Techno-economic evaluation under Canadian conditions.

Evaluation Framework (Conceptual)



8. Expected Outcomes and Future Work

- A comprehensive framework for real-time monitoring, intelligent control and optimal operation of data-centre electrical systems.
- Improved energy efficiency, power quality, reliability and cost-effectiveness.
- Guidelines for integration of renewable energy and multiple energy storage technologies.
- Comparison of grid-connected and off-grid operating scenarios for Canadian conditions.
- Future work: detailed modelling, simulation, optimisation and experimental validation.

9. Selected References

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